Project & Team

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Distributed and Electric Power System Aggregation Model Determination and Field Configuration Equivalency Validation Testing (AAD-0-30605-09)

Presented by:

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Distributed Power Program
Review Meeting
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Arlington, Virginia

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Project Team

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Organization	Team Members
DTE Energy Technologies Farmington Hills, Michigan	Murray W. Davis Ronald A. Fryzel (Retired)
Detroit Edison Detroit, Michigan	David Costyk Raluca E. Capatina-Rata Kenneth J. Pabian
Kinectrics Toronto, Ontario	Arun Narang E. Peter Dick

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Background and Objective

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Background

- Local electric distribution systems had not been designed to operate in parallel with local interconnected distributed power systems. As a result, issues arise about the compatibility, reliability, power quality, system protection and safety.

Objective:

- Address selected system integration issues arising from interconnecting distributed resource systems with the utility grid.

- Focus on DR system penetration that depends on limits imposed by the local grid due to the number of utility coordination issues, e.g., voltage dynamics, and system protection.

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Approach

Approach

- Select two working Detroit Edison distribution circuits for study
- Develop equivalent circuits and models
- Run simulations
- Determine DR penetration boundaries

Key Issues:

• System Protection	by Detroit Edison
• Voltage & Stability	by Kinectrics

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Approach Details

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Selected Circuits:
- 4.8kV D.C. 326 Argo (Ungrounded Delta)
- 13.2kV D.C 9795 Pioneer (Multi-grounded Wye)

Model and Study tools:
- Aspen, DEW (Protections)
- EMTP (Harmonics), MATLAB (V. Reg), PTI PSS/E (Stability)

Validation techniques:
- Spot check among tools, Simplified hand calcs.
- Software tools are proven commercial packages

Key DR elements
- 1000 kVA synchronous generator
- 400 kW inverter based gas turbine
- 250 kW inverter based fuel cell

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List of 29 EEI System Impact Issues

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EEI Issues Studied by Detroit Edison

Issue		Issue	
→ 1	Improper Coordination	→ 16	Isolate DR for Upstream Fault
→ 2	Nuisance Fuse Blowing	17	Close-in fault Causes Voltage Dip - Trips DR
3	Reclosing out of Synchronism	18	Switchgear Ratings
4	Transfer Trip	19	Self Excited Induction Generator
5	Islanding	20	Long Feeder Steady State Stability
6	Equipment Overvoltage	21	Stability During Faults
7	Resonant Overvoltage	22	Loss of Exciters Causes Low Voltage
8	Harmonics	23	Inrush of Induction Machines Can Cause Voltage Dips
9	Sectionalizer Miscount	24	Voltage Cancelled by Forced Commutated Inverters
10	Reverse Power Relay Malfunctions	25	Capacitor Switching Causes Inverter Trips
11	Voltage Regulation Malfunctions	26	Flicker from Windmill Blades
12	Line Drop Compensator Fooled by DR's	→ 27	Upstream Single Phase Fault Causes Fuse Blowing
13	LTC Regulation Affected by DR's	28	Underfrequency Relaying
14a	Substation Load Monitoring Errors	29	Distribution Automation Studies
14b	Cold Load Pickup with & without DR's		
→ 15	Faults within a DR zone		

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→ **Impact issues related to system protection**

List of 29 EEI System Impact Issues

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EEI Issues Studied by Kinectrics	
Issue 1 Improper Coordination 2 Nuisance Fuse Blowing 3 Reclosing out of Synchronism 4 Transfer Trip 5 Islanding 6 Equipment Overvoltage 7 Resonant Overvoltage 8 Harmonics 9 Sectionalizer Miscount 10 Reverse Power Relay Malfunctions 11 Voltage Regulation 12 Line Drop Compensator Fooled by DR's 13 LTC Regulation Affected by DR's 14a Substation Load Monitoring Errors 14b Cold Load Pickup with & without DR's 15 Faults within a DR zone	Issue 16 Isolate DR for Upstream Fault 17 Close-in fault Causes Voltage Dip - Trips DR 18 Switchgear Ratings 19 Self Excited Induction Generator 20 Long Feeder Steady State Stability 21 Stability During Faults 22 Loss of Exciters Causes Low Voltage 23 Inrush of Induction Machines Can Cause Voltage Dips 24 Voltage Cancelled by Forced Commutated Inverters 25 Capacitor Switching Causes Inverter Trips 26 Flicker from Windmill Blades 27 Upstream Single Phase Fault Causes Fuse Blowing 28 Underfrequency Relaying 29 Distribution Automation Studies

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→ **Impact issues related to voltage dynamics and stability**

D.C 9795 Pioneer Overview

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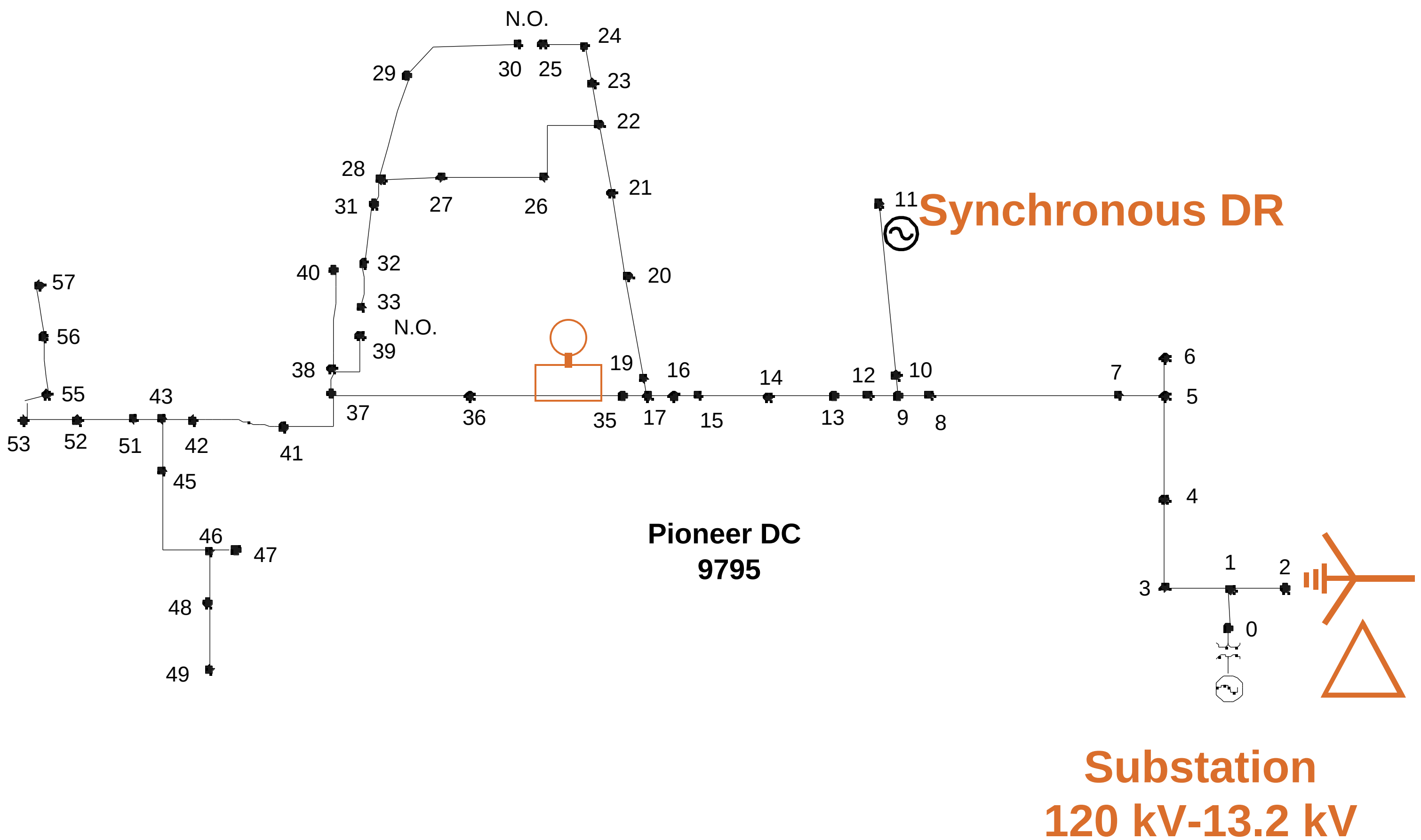

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D.C 326 Argo Overview

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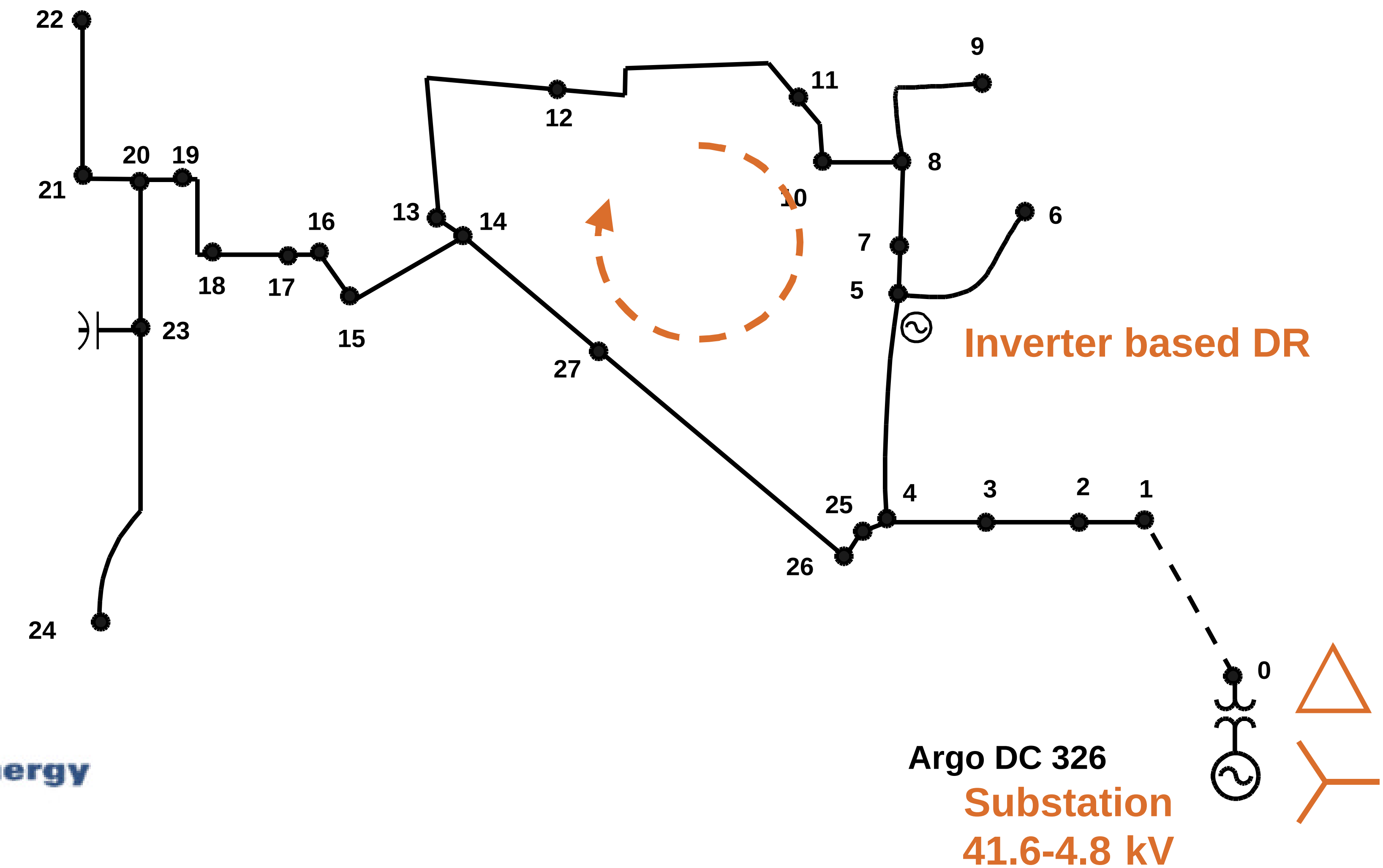

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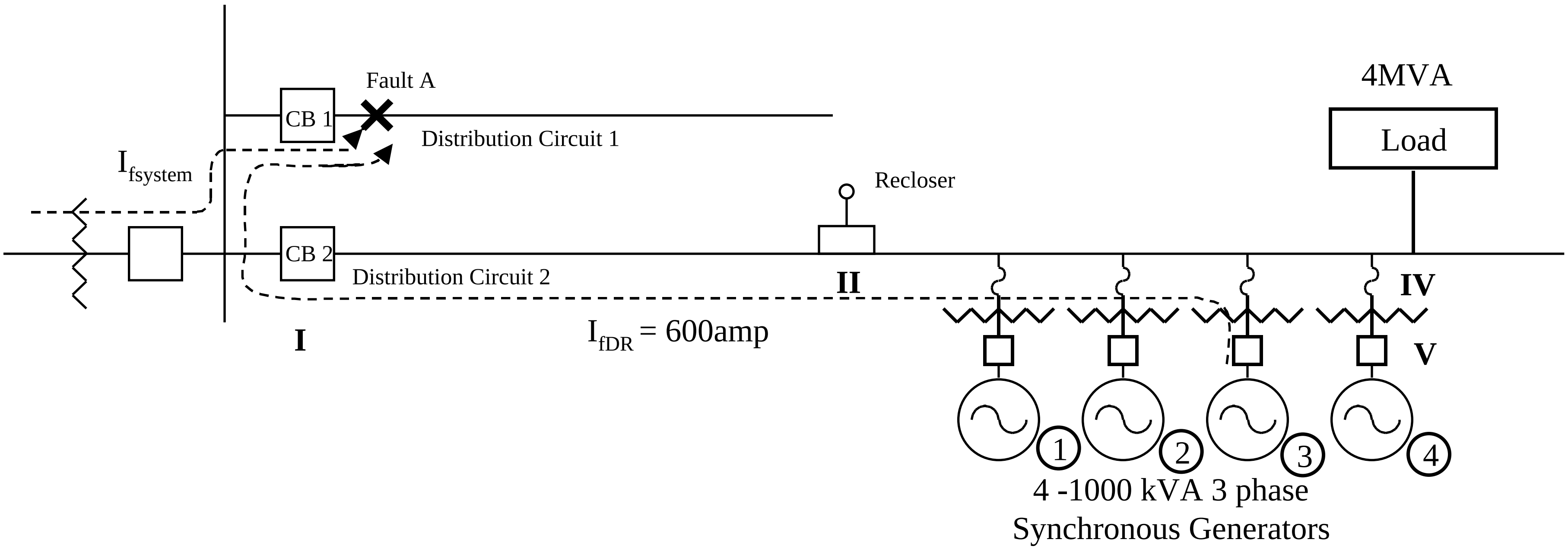
Issue 1: Improper Coordination One-Line

Example



1. For various fault current levels, fuse sizes, recloser sizes and breaker trip currents determine limits of DR penetration to cause inselectivity

2. Aspen, DEW and hand calculations were consistent.

Issue 1: Improper Coordination Relay and Recloser curves

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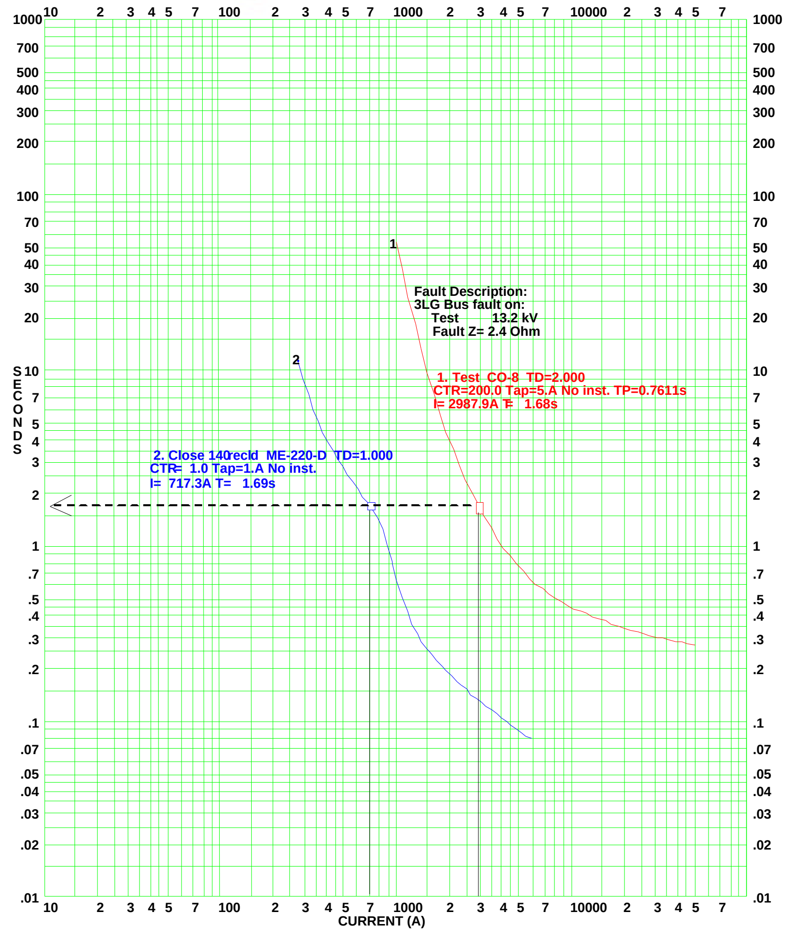
Plot does not permit viewing a selectivity range

Plot does not make effect of DR size change obvious

To Make a better Plot:

- **Determine breaker trip time for a current**
- **Determine recloser current for that same time**
- **Calculate system current (Breaker-Recloser)**
- **Plot each Recloser Current vs System current over a range**



TIME-CURRENT CURVES @ Voltage		By
For	2.4 ohm fault impedance, 15 MVA Sub trans 11 MVA DR	No.
Comment	Fault impedance and DR size adjusted to illustrate selectivity margin	Date

Plot of time current curves for substation breaker relay and 140a recloser.

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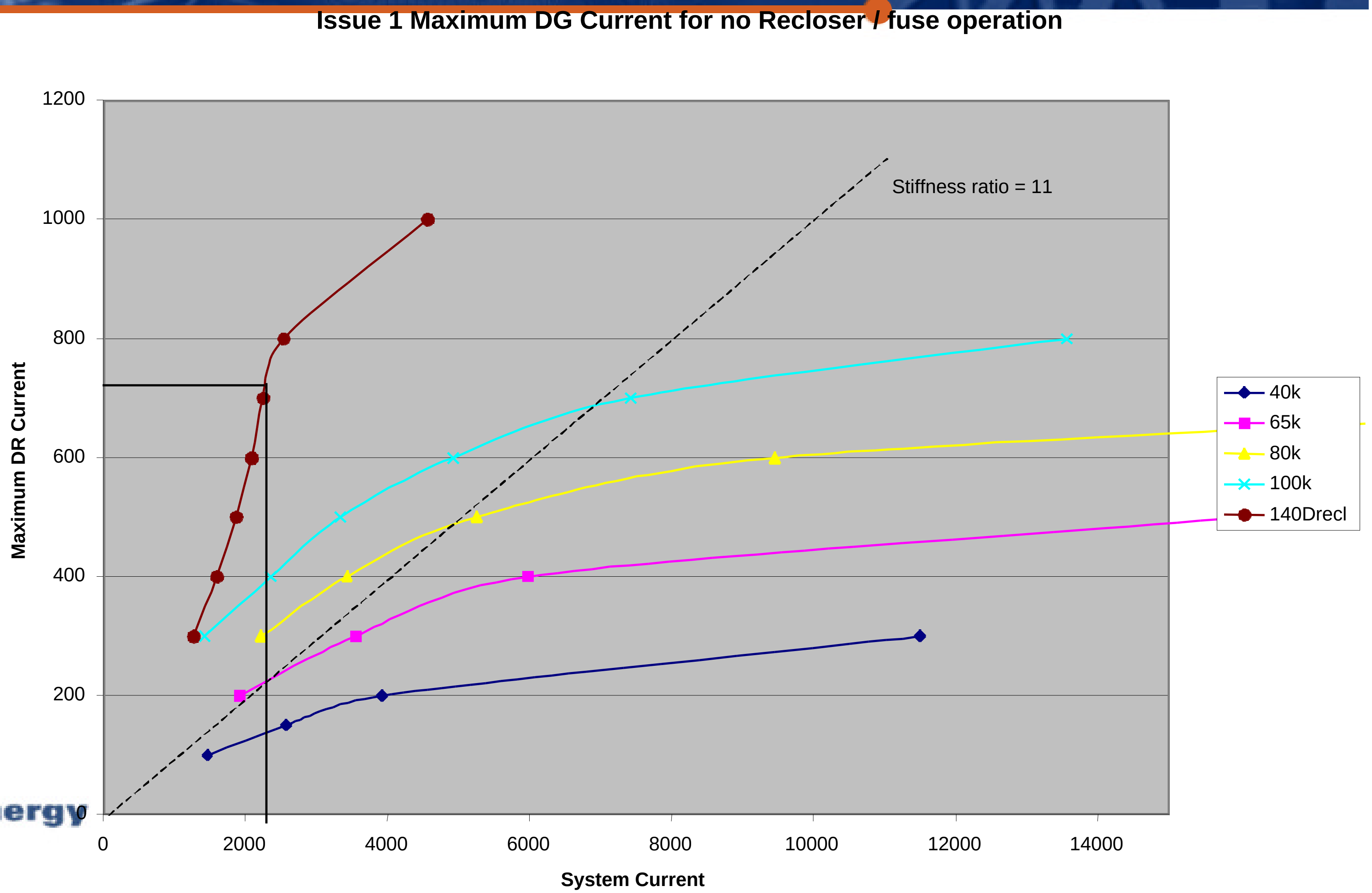
Issue 1 Improper Coordination Penetration Limit Results

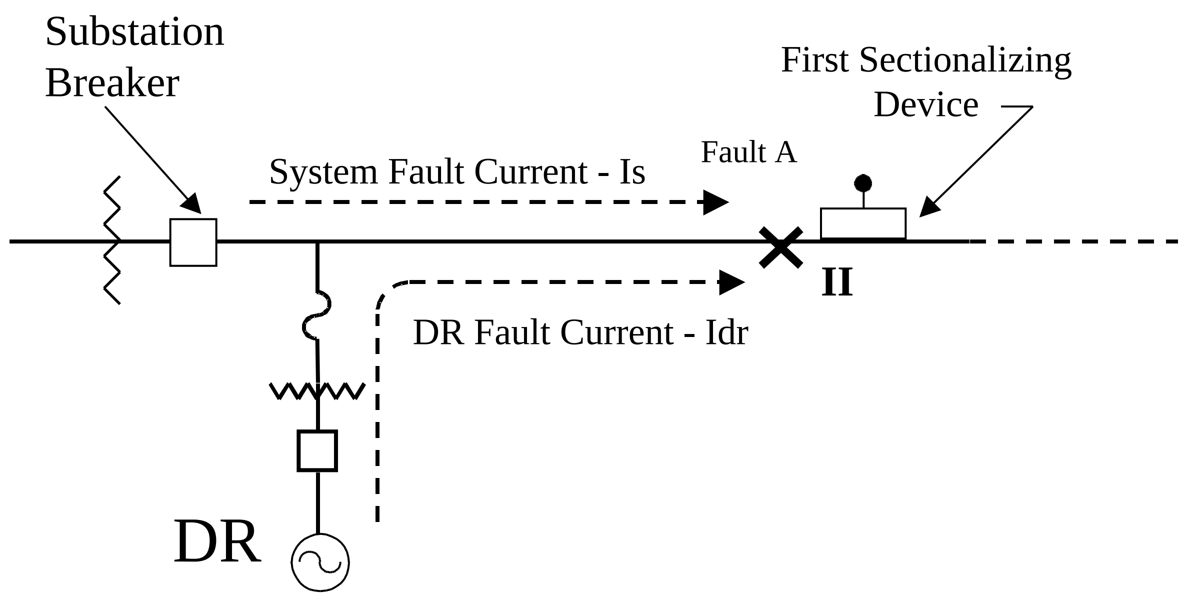


Issue 1 Fault Detection Sensitivity One-Line

Scenario

- Fault at point A as shown below.
- Fault is near the line protection device that has the least available fault current at its location.
- The substation breaker will typically not be required to sense faults beyond this device.
- Fault current contribution from DR reduces fault contribution from substation

•Protective device at substation takes longer to trip or does not trip until DR trips



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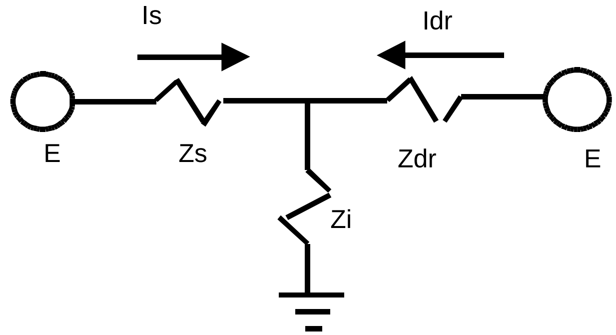
Issue 1: Improper Coordination Infeed Table

Table to Show Source Current (Is) and DR Current (Idr) for various Per Unit Source and DR Impedances (Three phase faults only)

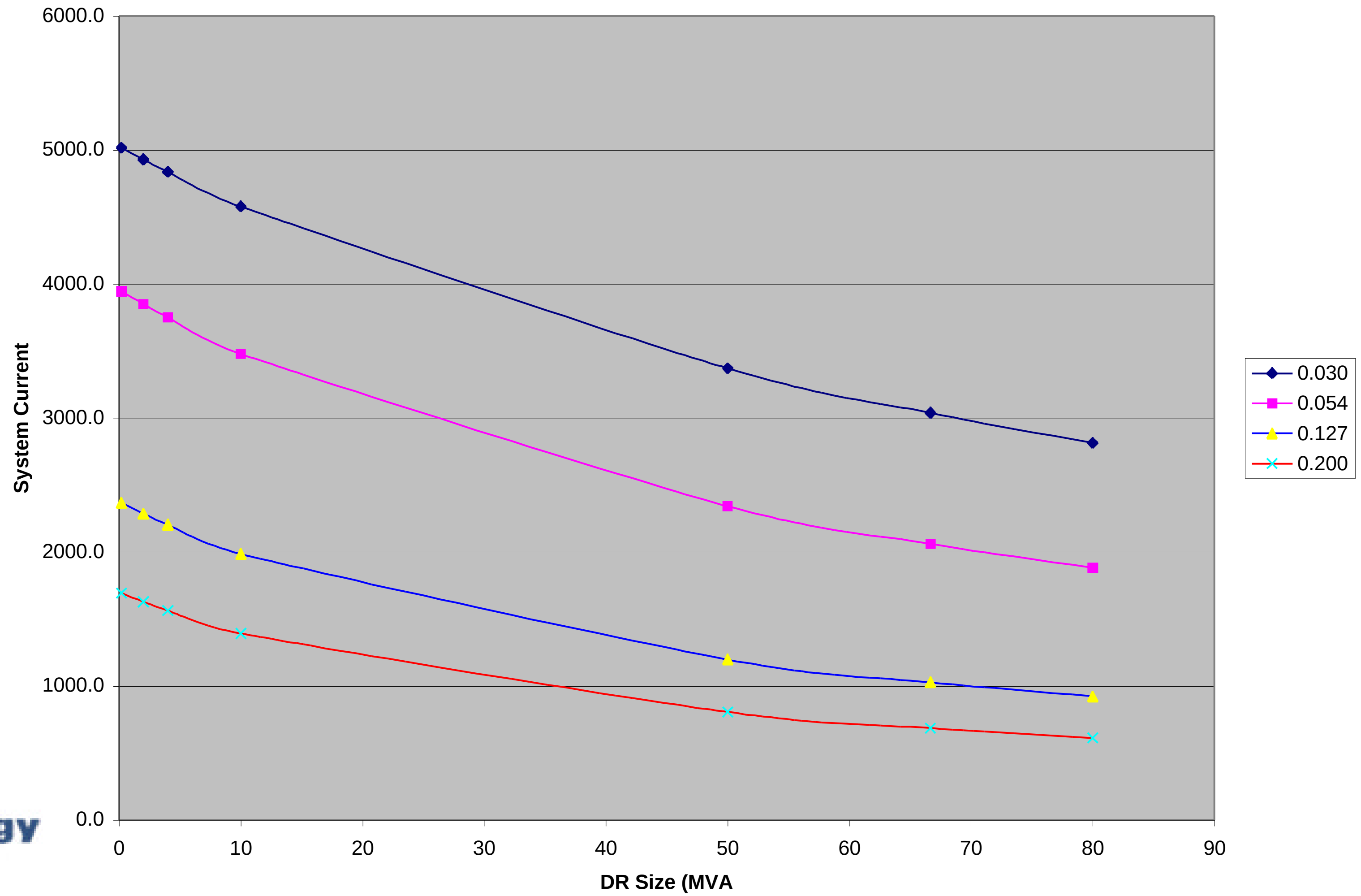


Make Entries in Blue Shaded Area only!!!

MVA Base=	10	Is=Zdr/(Zdr+Zs)E/((Zdr*Zs)/(Zdr+Zs)+Zi)
kV Base =	13.2	Id=Zs/(Zdr+Zs)E/((Zdr*Zs)/(Zdr+Zs)+Zi)
I base =	437.3866	Zdr=(Zi*Zs)/((E/Is-(Zs+Zi))
Z base =	17.424	
DR PU Z =	0.2	(to calculate DR size)
All Z in P.U.		E= 1.0
Zs=	**0.057**	

		Charted			Charted			Charted	Charted
	Zi ->	**0.030**	**0.050**	**0.060**	**0.054**	**0.080**	**0.090**	**0.127**	**0.200**
DR MVA size	**Zdr**	**Is**							
80	**0.025**	2814.6	1979.1	1723.4	1881.4	1369.4	1241.9	923.6	613.4
66.66666667	**0.03**	3037.4	2165.3	1893.4	2061.7	1513.4	1375.4	1028.4	686.6
50	**0.04**	3371.0	2453.8	2159.9	2342.3	1742.6	1589.1	1198.4	807.0
10	**0.2**	4577.6	3607.3	3261.6	3478.3	2737.1	2533.4	1986.4	1393.0
4	**0.5**	4837.3	3881.0	3531.9	3751.2	2993.3	2781.3	2203.7	1563.2
2	**1**	4930.5	3981.7	3632.2	3851.9	3089.8	2875.1	2287.1	1629.6
0.2	**10**	5017.6	4076.9	3727.5	3947.4	3182.0	2965.1	2367.8	1694.4

Issue 1 Fault Detection Sensitivity Infeed Chart



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Sensitivity Conclusions

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1. Line to Ground faults restrict the DR size much more than 3 phase faults (Assuming ground fault current contribution by DR)

2. Coordination charts can help visualize the effect of DR penetration

3. Line length has a major effect on DR penetration boundary

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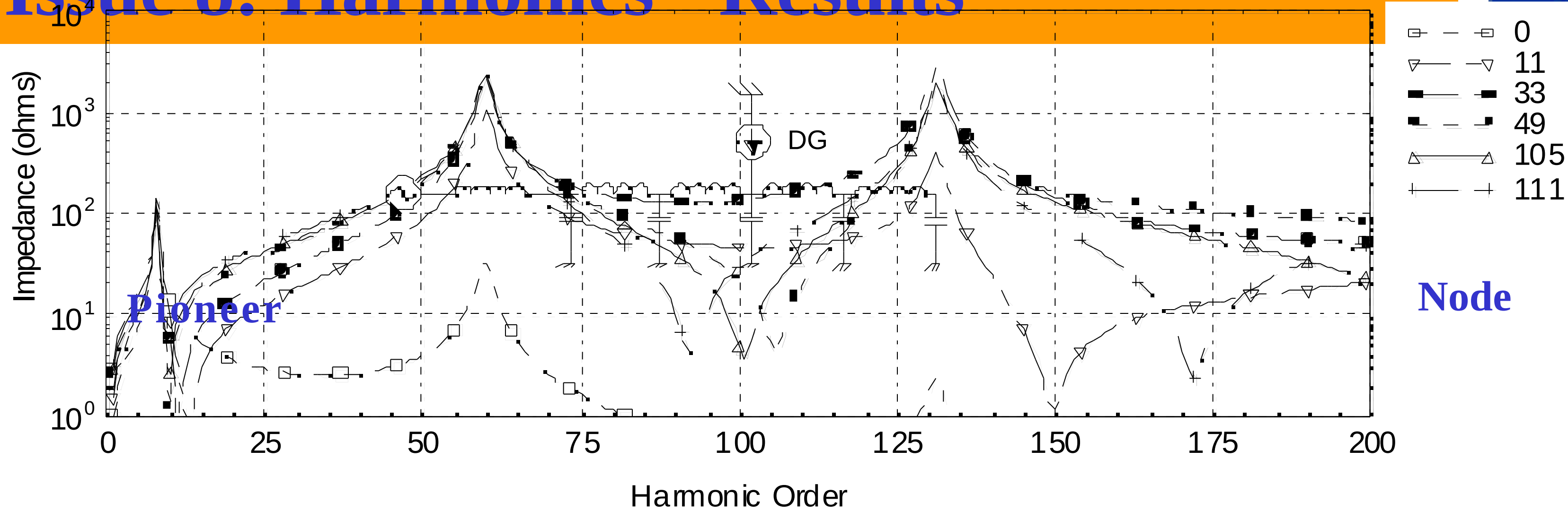
Issues Studied & Tools

• Harmonics	✓ *EMTP*
• Voltage Regulation	✓ *MATLAB*
• Steady-state stability	✓ *PTI PSS/E*
• Transient Stability	✓ *PTI PSS/E*

Issue 8: Harmonics - Results



- Resonance at PWM frequencies due to longfdrs, or shorter fdrs with cable laterals
- Resonance at LCI frequencies due to nearby VAR compensation
- Resonance may amplify voltage distortion due to inverter current harmonics

Issue 8: Harmonics - DG Penetration Limits

KINECTRICS

Pioneer - 6.8 MVA Pk Load

LCI Based DG: 900 kVA

PWM Based DG:

single 900 kVA unit

or 100 x 90 kVA units

Argo - 2.2 MVA Pk Load

LCI Based DG: 700 kVA

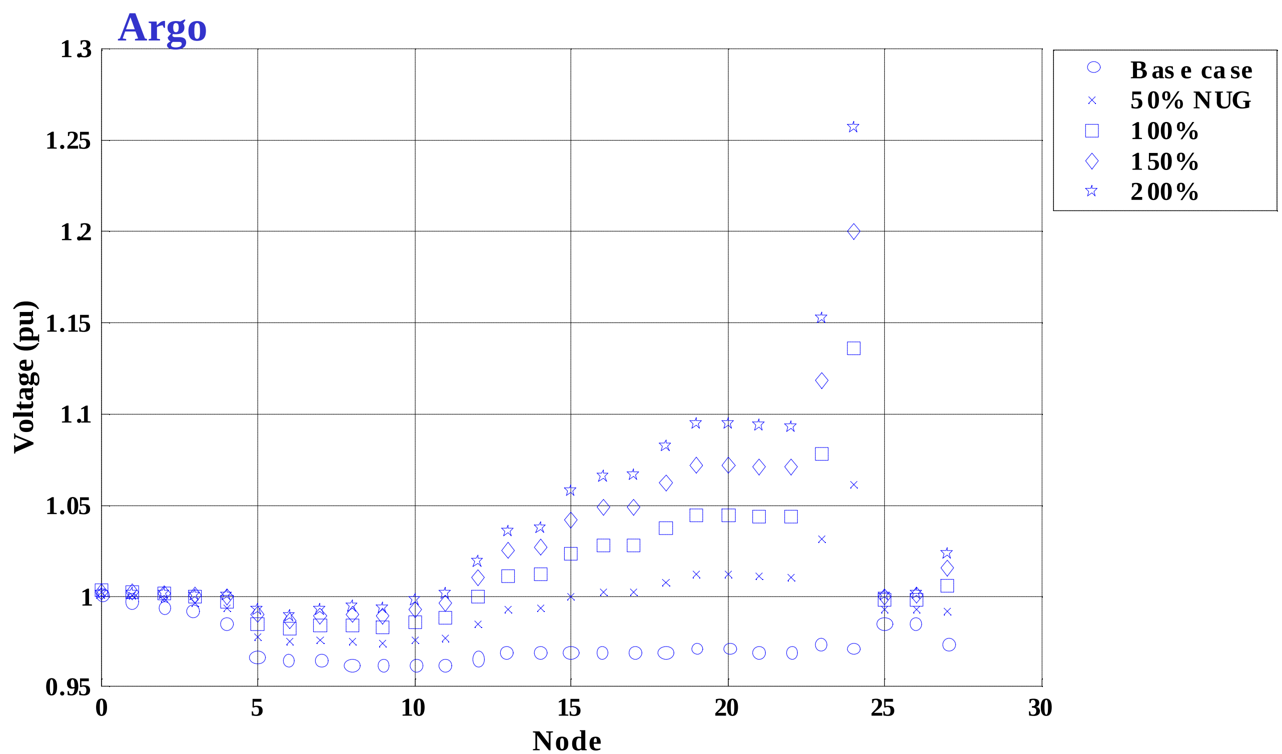
PWM Based DG:

single 230 kVA unit

or 100 x 20 kVA units

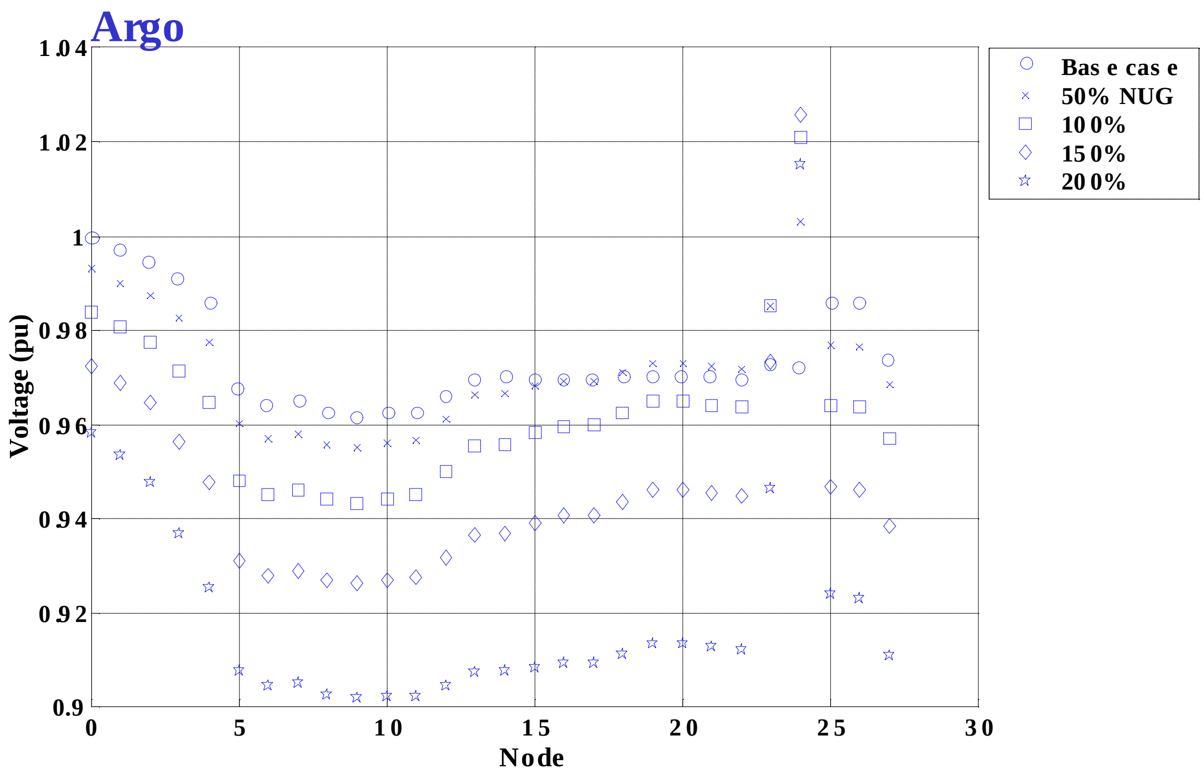
- relatively insensitive to **feeder loading**, **stiffness ratio**
- assumes current and voltage harmonic limits per IEEE 519
- assumes harmonic cancellation for multiple PWM inverter units
- based on voltage amplification at feeder resonance frequencies (conservative?)

Issue 11: Feeder Voltage Regulation



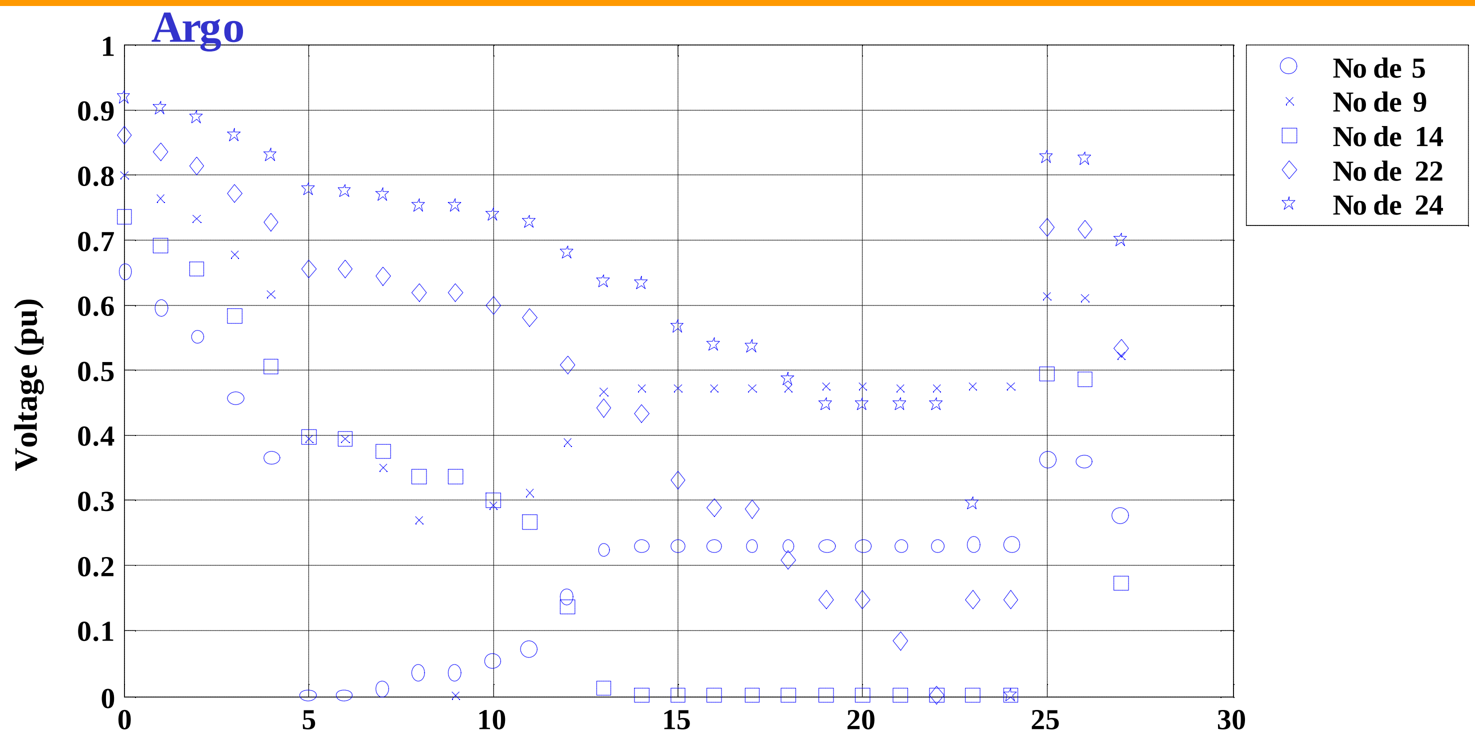
- Assumes DG at unity power factor
- % DG rating relative to peak load
- DG > 50% pk load may require attention (stiffness ratio 25)

Issue 11: Feeder Voltage Regulation - Argo



- Allowing DG to regulate voltage improves V profile
- DG to 200% peak load may not require new measures (stiffness ratio 4-5)

Voltage Profile due to 3-phase bolted Fault on Fdr



- Faults (3-phase bolted) near head-end of feeder result in transient instability for > 0.1 s clearing time
- For faults at far end of adjacent feeders, residual station-bus voltage may be sufficient to double permissible fault clearing time for maintaining DG stability.

Issue 21:Stability Study - Conclusions

- Steady-state stability is unlikely to be a limiting constraint

  Permissible DG rating >> 200% peak load

- Transient Stability: 3-phase faults on adjacent feeders

  - *DG unlikely to avoid instability (~ 1 s clearing time)*
  - *High-inertia DG's (H >1 MW-sec/MVA) or faster fault clearing (<0.2 s) would help*

General Conclusions

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1. Applicability of models was validated by comparison among proven tools.

2. Studies on 2 specific circuits have led to the development of methods of analysis that expedite the process of determining DR penetration limits.

3. Protective device coordination charts can be developed that are instructive and generally applicable

4. More work is needed to make these methods easily applicable for use by those performing day-to-day system studies involving DR.

5. Rules of thumb involving stiffness ratio are helpful and instructive but device sizes are also very important.

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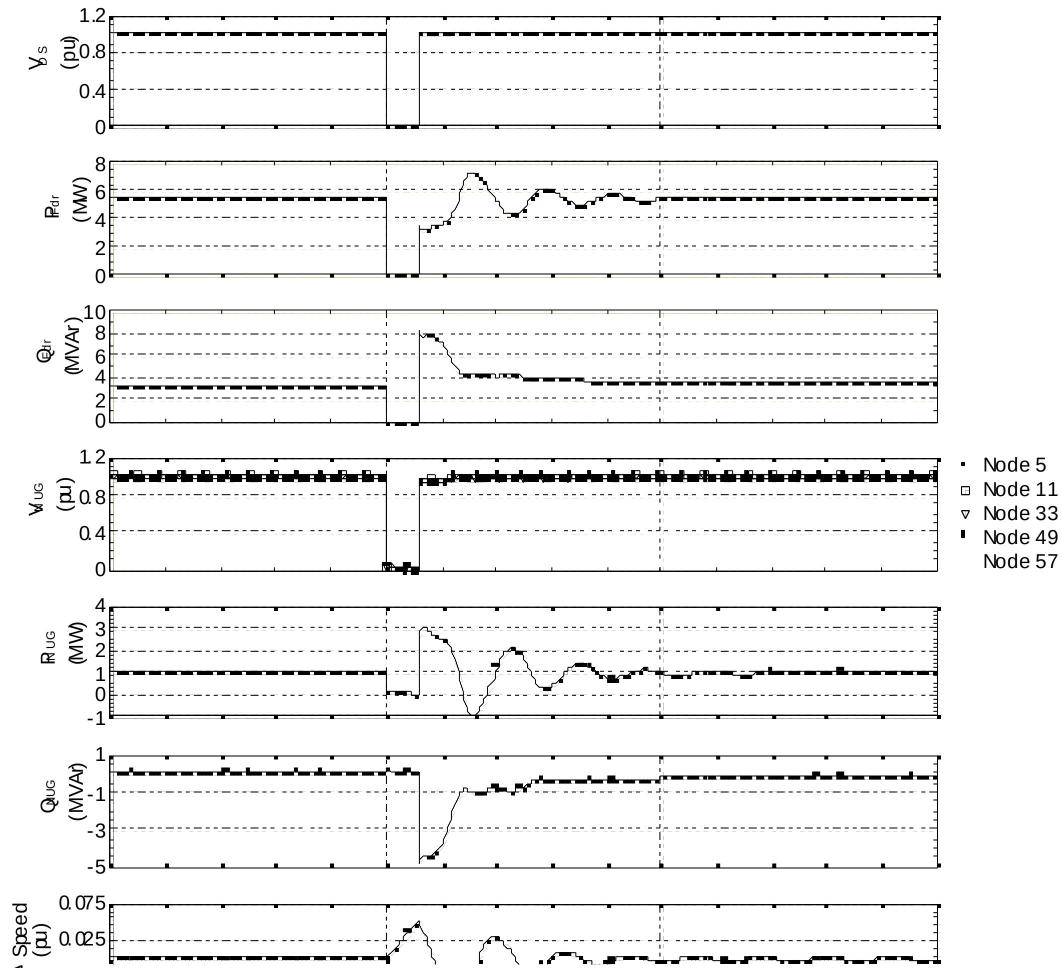
The following slides are reference only

Transient Stability

DG at Node 57, Fault on DS Bus Cleared in 0.11 s



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Issue 2: Nuisance fuse blowing One-Line

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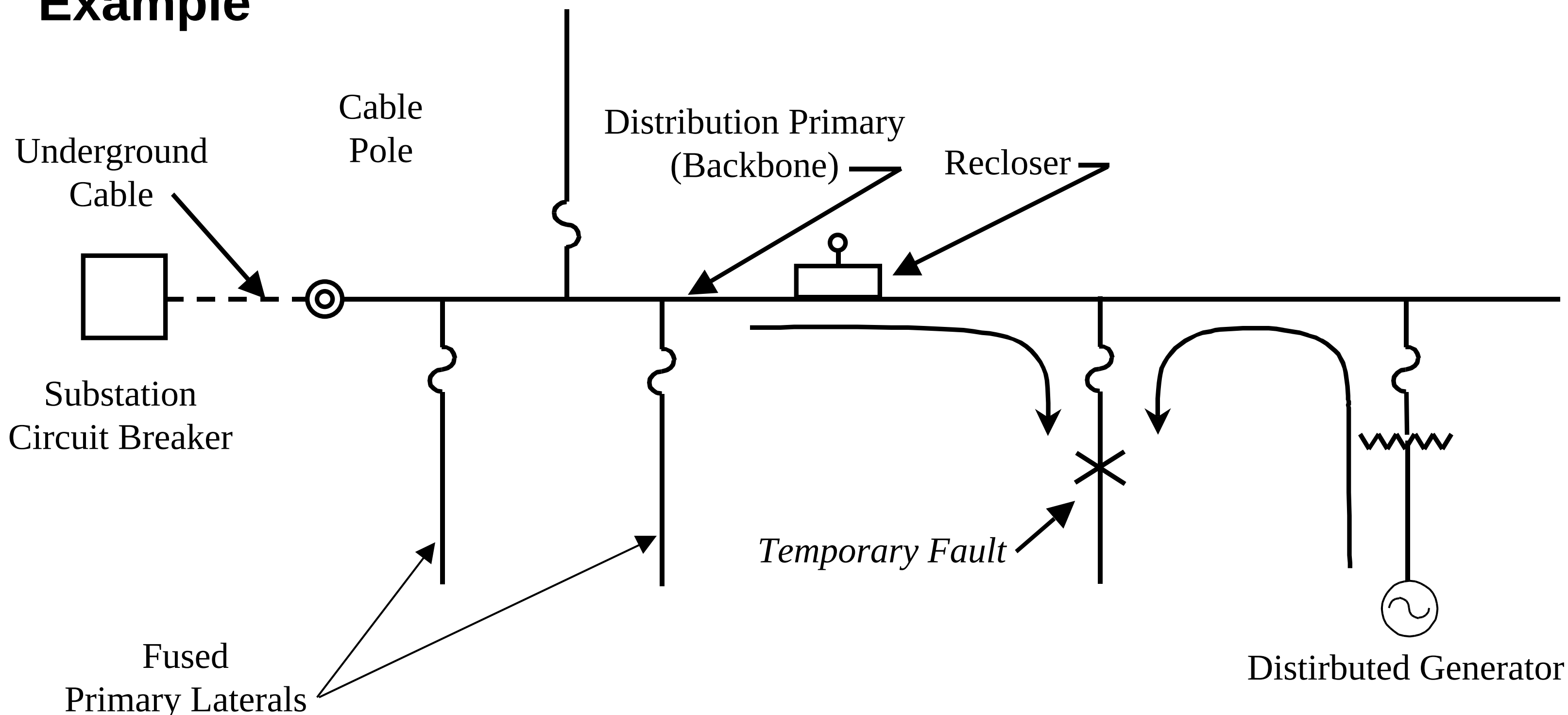
Example



1. For various fault current levels, fuse sizes, recloser sizes and breaker trip currents determine limits of DR penetration to cause inselectivity
2. Compare Aspen and DEW results

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Issue 2: Nuisance fuse blowing Recloser and Fuse Curves

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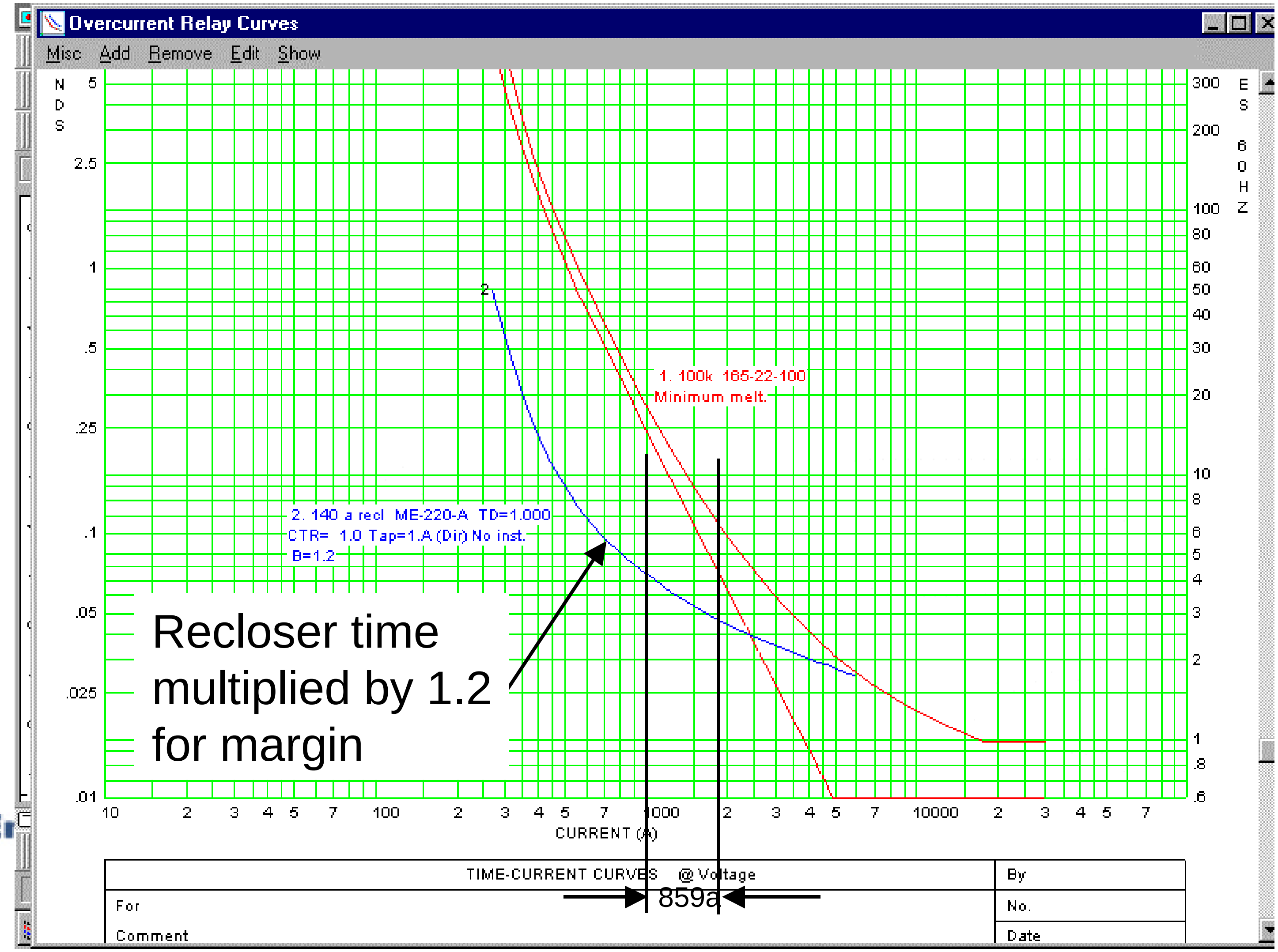

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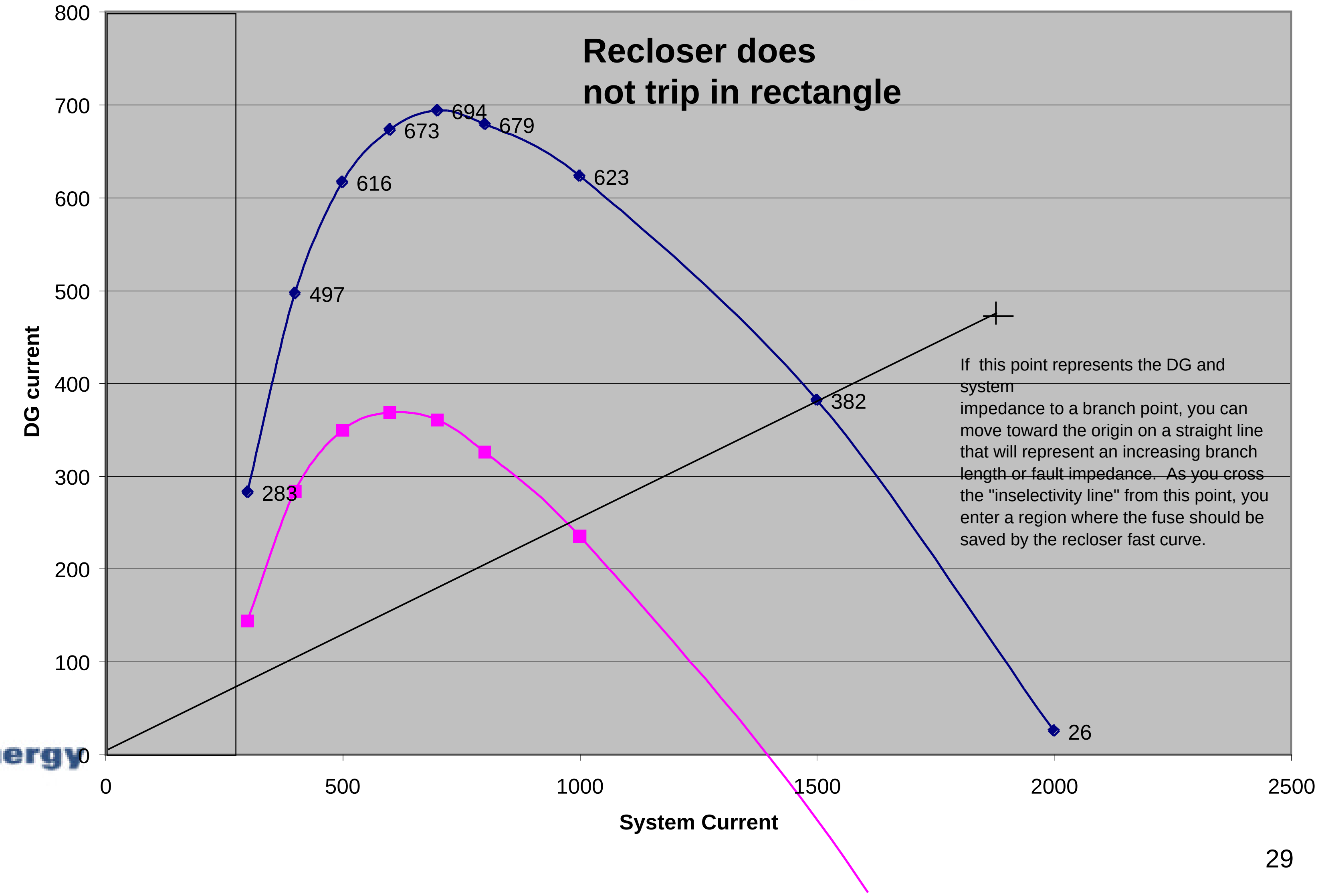
Issue 2: Nuisance fuse blowing

Penetration Limits for 80k fuse and 140a V4L recloser



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Issue 2: Fuse saving Conclusions

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1. For a low system fault current, and large fuse size the boundary of DR size is relatively large
2. For a large system fault current, and a large fuse size, then the lower the boundary of DR size
3. For a low system fault current and a small fuse size, then the boundary of DR size is relatively small.
4. For a large system fault current and a small fuse size, then the boundary of DR size is even smaller.

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Issue 2: Fuse saving Conclusions

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5. For all fuse sizes where the relationship between DR fault current has a negative slope, the boundary of DR size decreases as the system fault current increases.

▪

6. Notice when the stiffness ratio is large and system fault current is large, then the boundary of DR size lower when compared with small fault currents and low stiffness ratio.

   Therefore, fuse size and system fault current are more relevant parameters than stiffness ratio in determining boundary for DR size.

7. For a fixed system fault current increasing stiffness results in lower DR fault current (by definition). Therefore as stiffness increases the selectivity margin increases.

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Overview of D|tech's Subcontract

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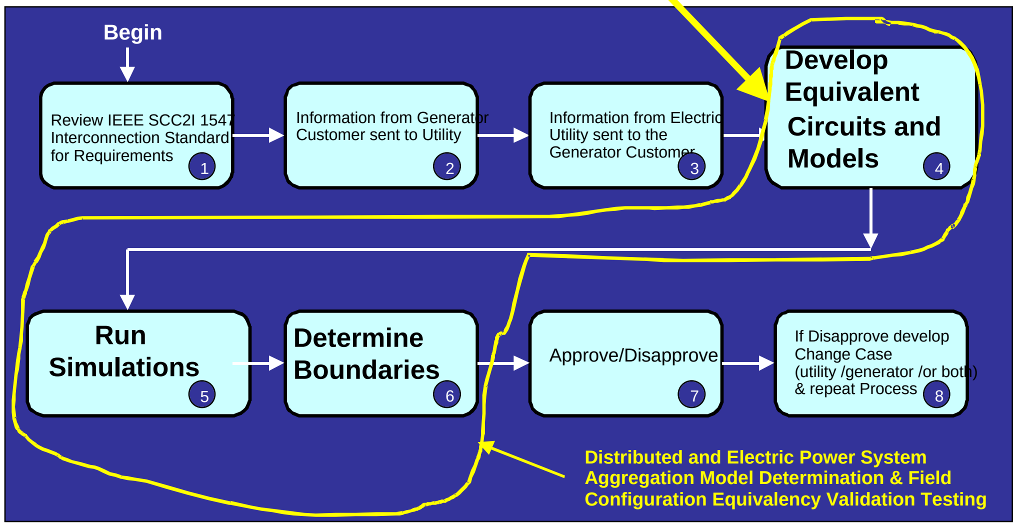
The Project Team will select & model two of Detroit Edison's distribution circuits and determine the impact of DR connection on circuit voltage and protection equipment .

- 2-800 kW (synchronous) and 400 kW inverter based generation
- Kinectrics focused on area of voltage dynamics including stability
- Detroit Edison focused on circuit protection issues
- This project supports the work of IEEE SCC21 1547 and proposed testing (analysis + evaluation) requirement



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D.C. 9795 Pioneer - Aspen Diagram

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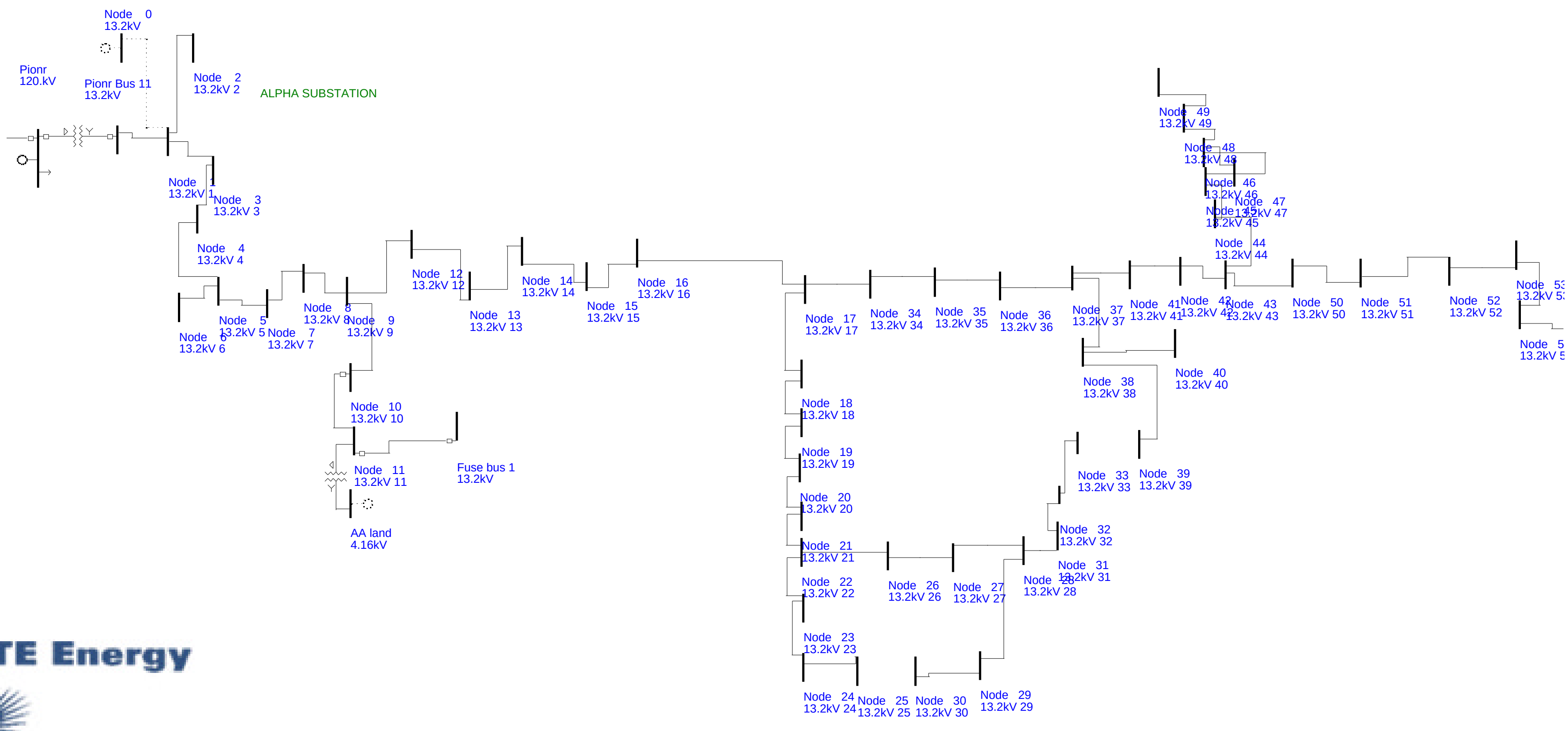

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D.C. 326 Argo - Aspen Diagram

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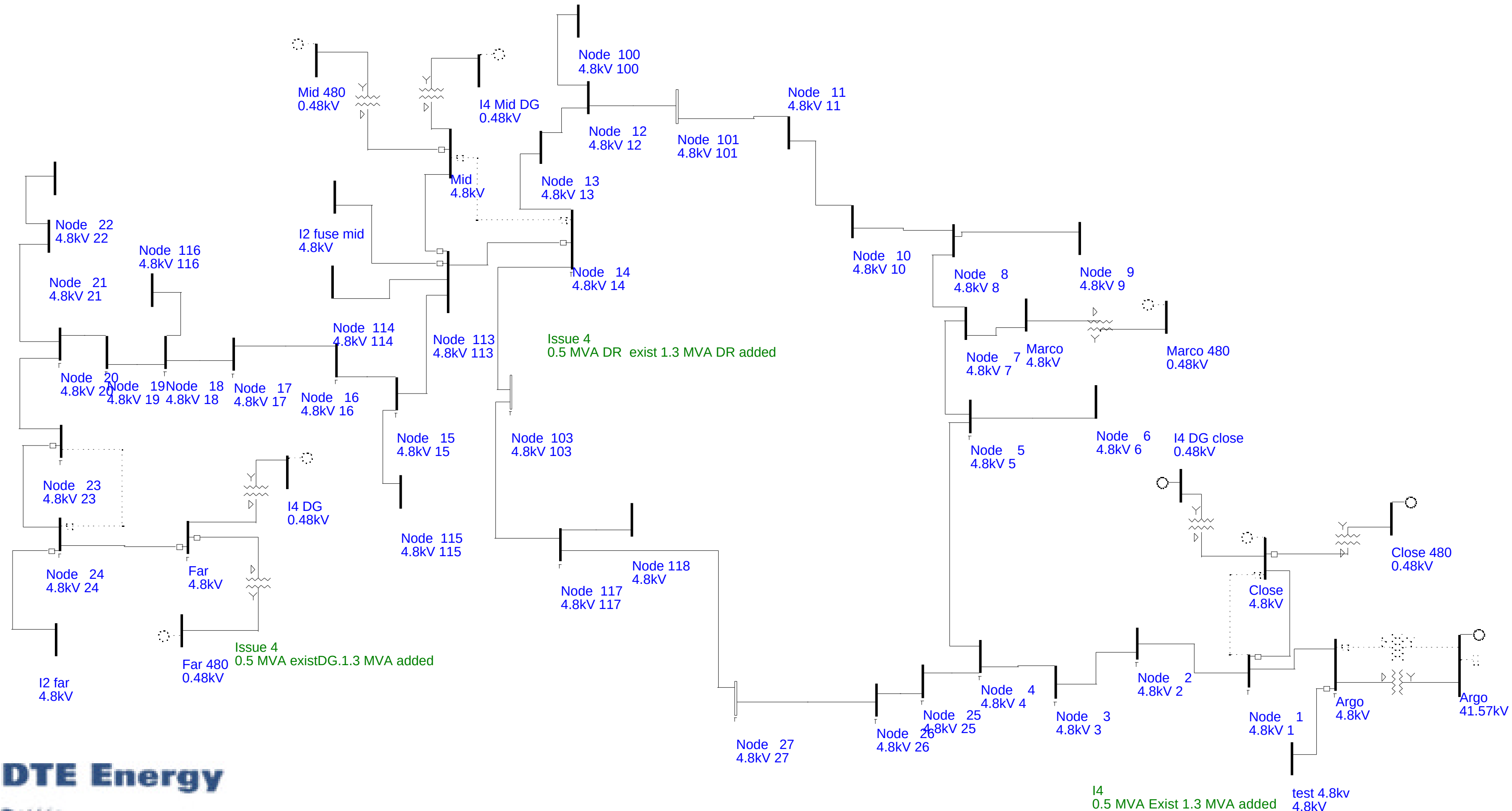

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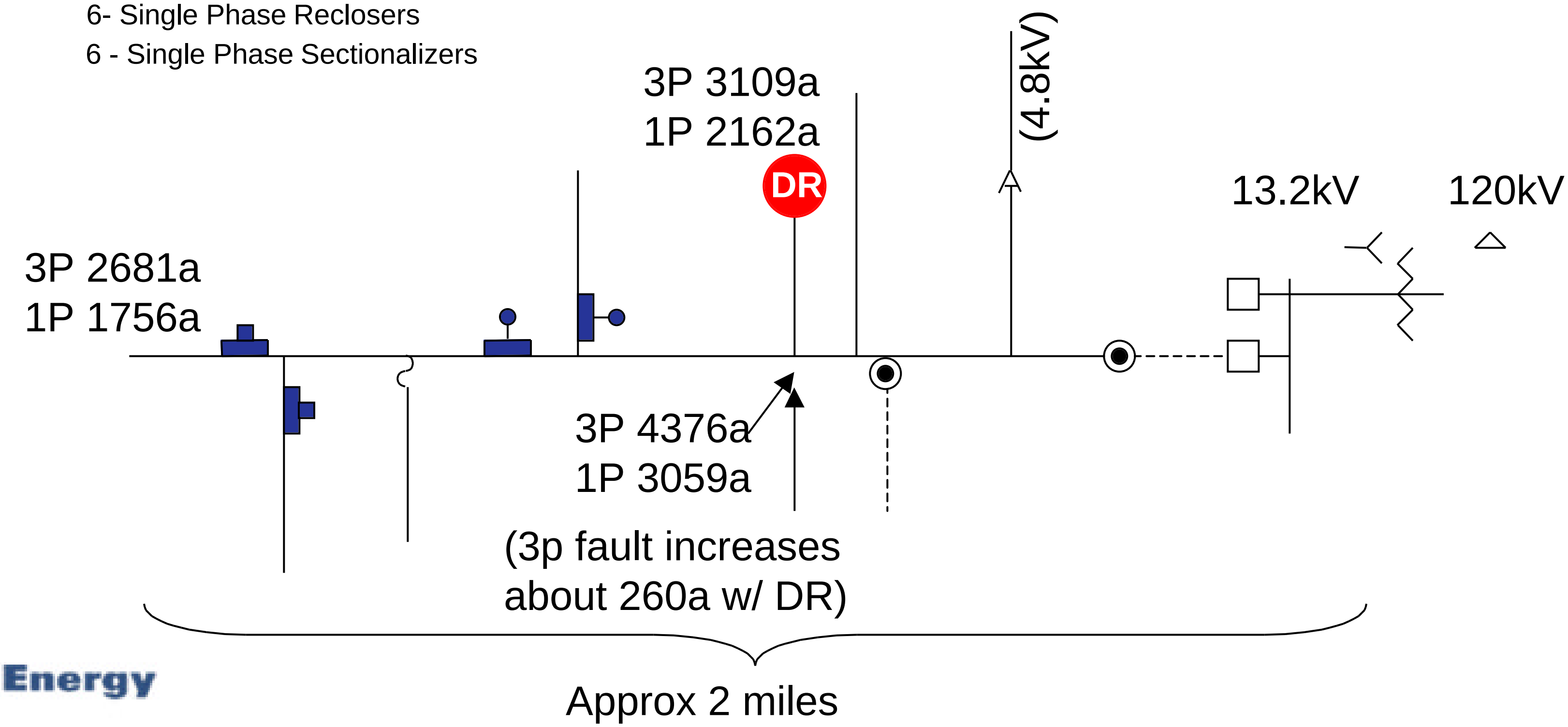
Sub Task 1.2 Results -- DC 9795 Pioneer 13.2kV

- Peak Load: 7351 KVA
- Number of buses: 57
- Overhead devices: 1-150 kVa 13.2-4.8 kV transformer
- Circuit Protection: Substation Breaker
  6- Single Phase Reclosers
  6 - Single Phase Sectionalizers



Sub Task 1.2 Results -- DC 326 Argo 4.8 Ungrounded / One Ring

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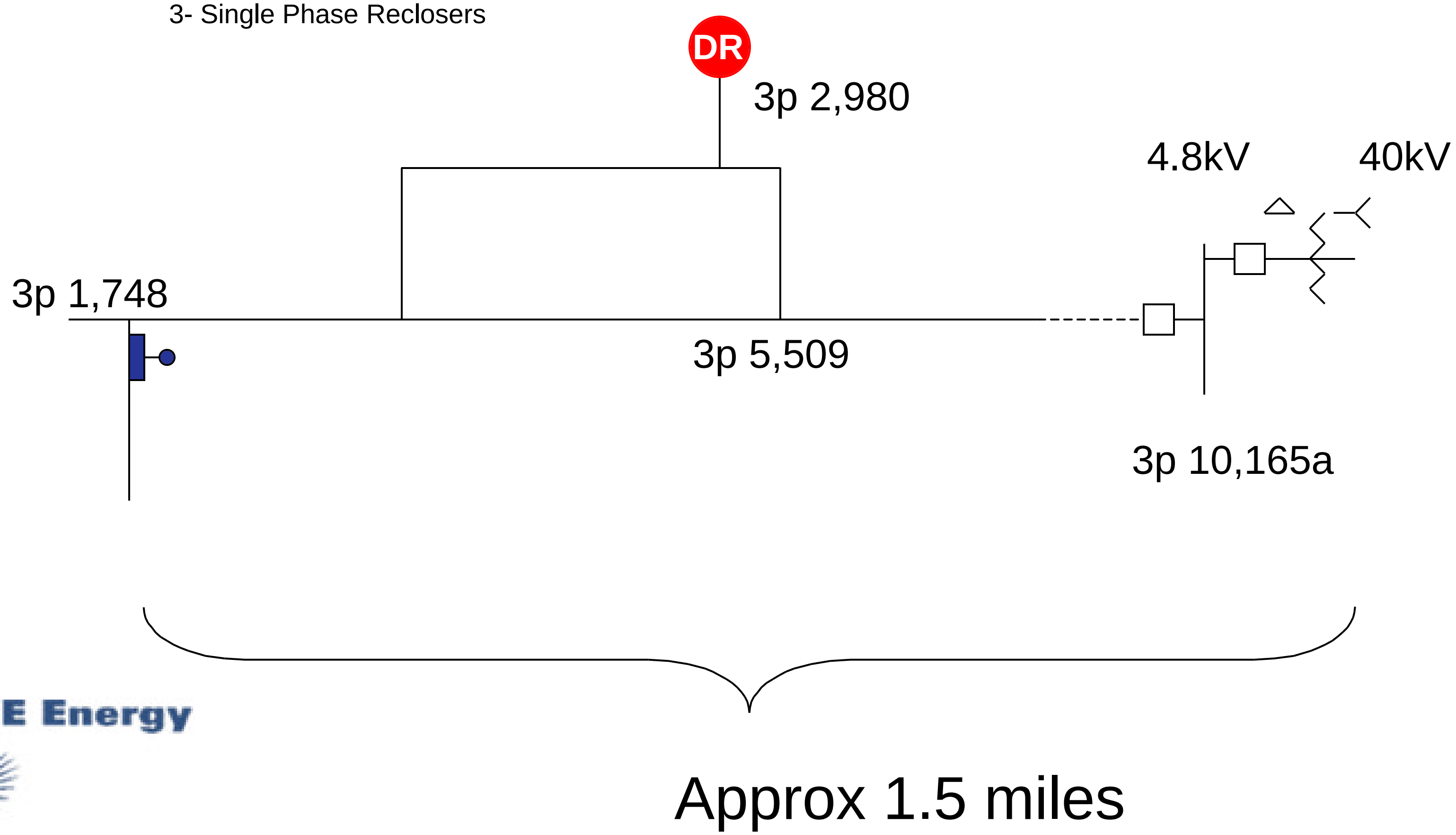
- Peak Load: 2175 KVA
- Number of buses: 27
- Overhead devices: 600 kVar Capacitor
  3-100 kVa Boost Regulators
- Circuit Protection: Substation Breaker
  3- Single Phase Reclosers



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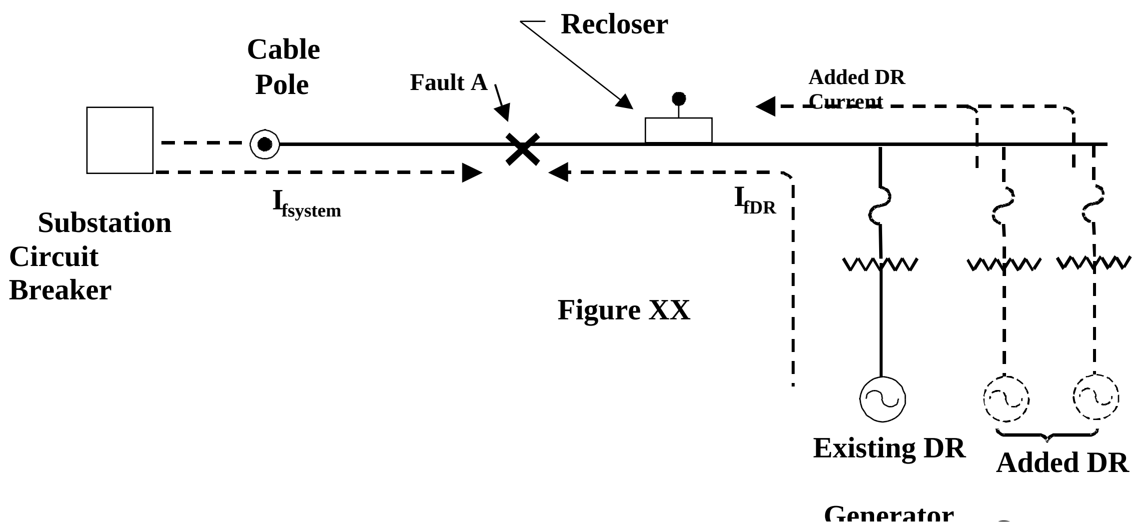
Issue 17: Isolate DR for Upstream Fault



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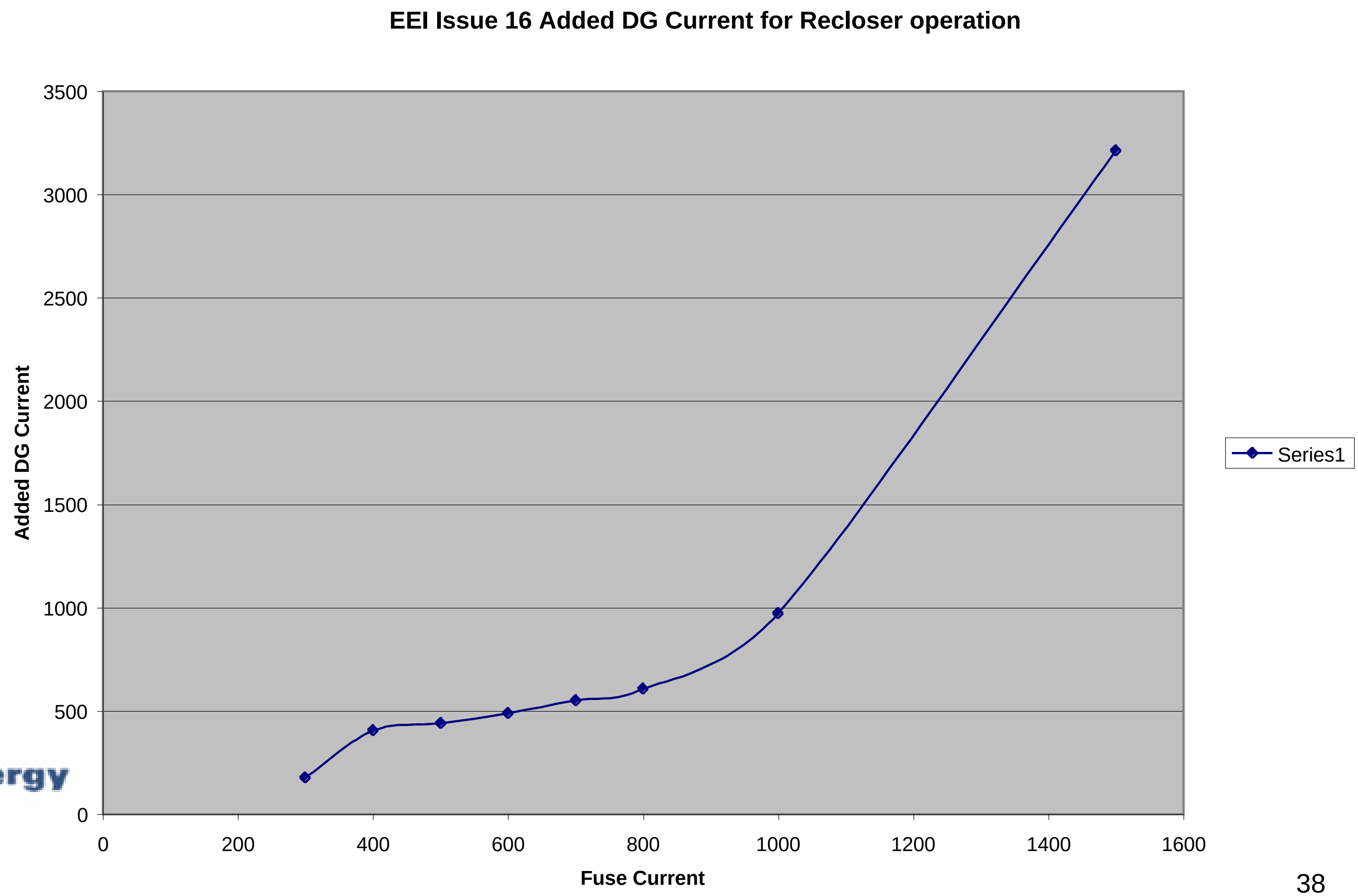
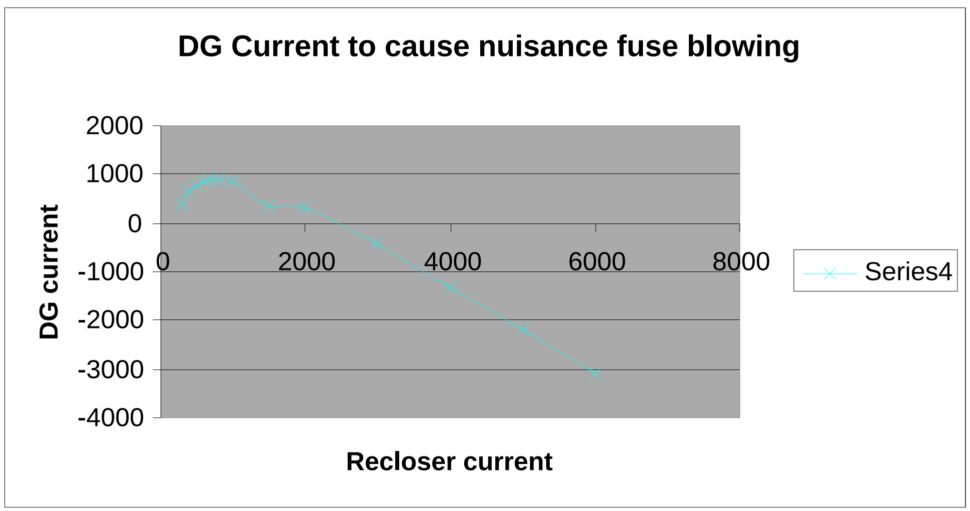
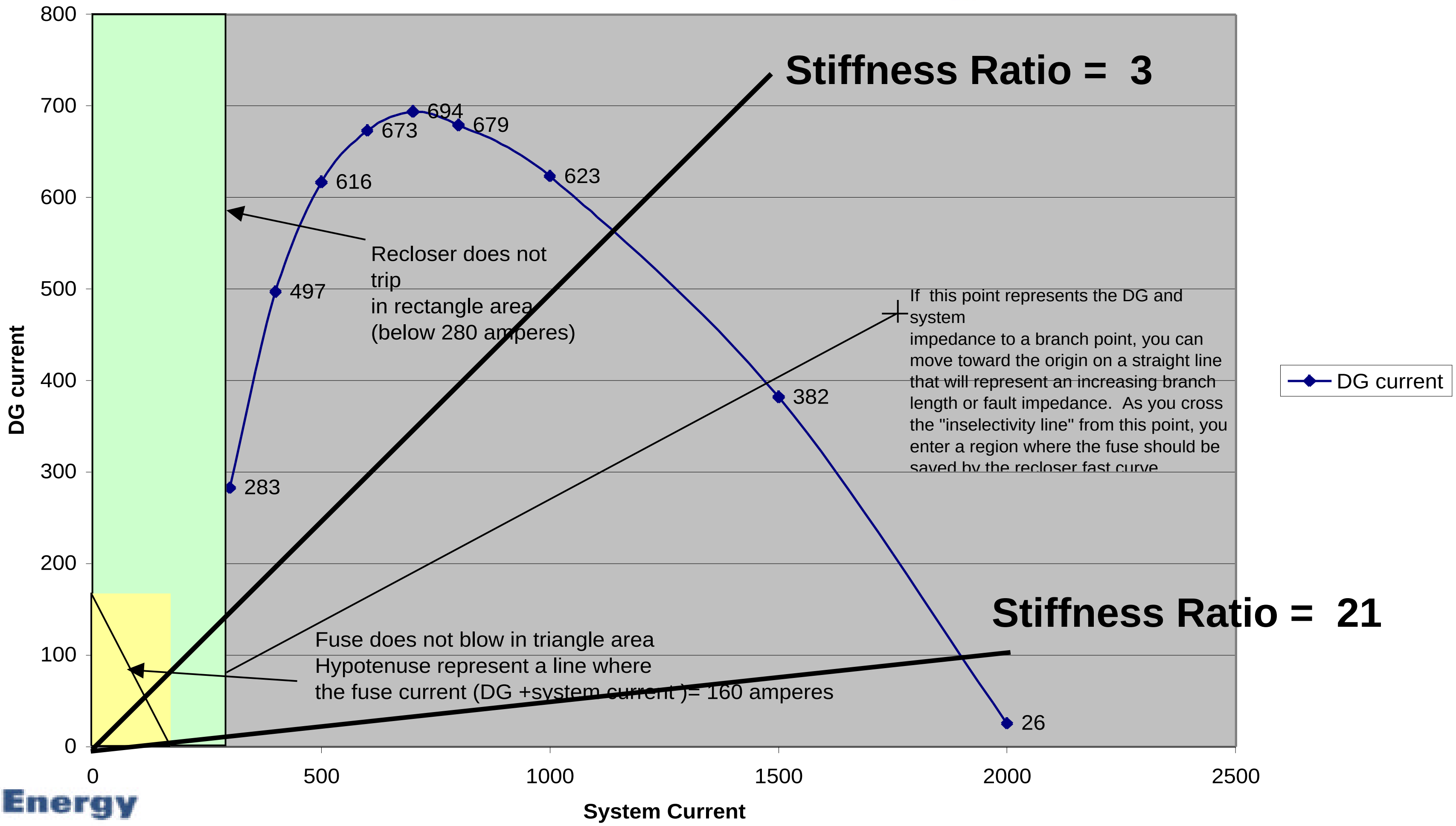

EEI Issue 16 Added DG Current for Recloser operation
Added DG Current
Fuse Current
0
500
1000
1500
2000
2500
3000
3500
0
200
400
600
800
1000
1200
1400
1600
Series1

Contingencies: Typical Spreadsheet Model Output

3000	2000	1500	1000	800	700	600	500	400	300	200	150	100	current
0.027	0.061	0.11	0.25	0.393	0.515	0.703	1.062	1.905	4.804				100k time
0.0372	0.0456	0.0528	0.0708	0.0852	0.096	0.1152	0.15	0.2328	0.57				recloser time
37.2	45.6	52.8	70.8	85.2	96	115.2	150	232.8	570				1000xRecl time
2557.893	2311.501	1857.126	1859.772	1699.134	1603.016	1466.169	1286.964	1035.831	665.685				fuse current for same time as recloser time
-442.107	311.5012	357.1257	859.7722	899.1344	903.0163	866.1694	786.9642	635.8313	365.685				DG current for non fuse saving
-0.14737	0.155751	0.238084	0.859772	1.123918	1.290023	1.443616	1.573928	1.589578	1.21895				Ratio of DG current to Recloser current



DG current
For 80k fuse and 140a V4L recloser



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Conclusions

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1. Sub-Tasks 2.1, 2.2 and 2.3 are behind schedule but current plans will result in completing them by the end of August.

2. We expect Sub-Tasks 3 and 4 to be completed on schedule

3. Major concerns going forward are:
   (a) validation of the DEW generation models
   (b) prudent selection of contingencies for detailed study that can produce high quality results with respect to system protection

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Inverter Characterization

Table D-1.3.2 Inverter Characterization						
Manufacturer		**FCE**			**Turbogenset**	
		200kW			**400kW**	
Rated Current		300 amps			600 amps	
Rated PF.		+/- 0.8			+/- 0.8	
Rated Voltage		480v Wye			480v Wye	
Voltage Limits		75%-120%			75%-120%	
Current Unbalance limits		50%			50%	
Voltage unbalance limits		no limit			no limit	
Maximum current output		600			1200	
THD		<2%			<2%	
Harmonic Tolerance		2%			2%	
Voltage Regulator Time constant		10ms			10ms	
Protective trip settings						
Underfrequency		59.3 hz	10s		59.3 hz	10s
Overfrequency		60.5 hz	10s		60.5 hz	10s
D.C. Current Limit		0.5% per phase			0.5% per phase	
Undervoltage		95%	2s		95%	2s
Undervoltage		75%	3 cycles		75%	3 cycles
Overvoltage		120%	3 cycles		120%	3 cycles

Generator Characterization

Table D-1.3.1 - Lafayette Power Systems Generator Characterization			
Arrangement No.	7C-4914		
Generator Parameters			
Ratings			
Line to Line Voltage	4160	Volt	
Line to Neutral Voltage	2402	Volt	
kVA rating	1000	kVA	
Rated RMS Current	139	Amps	
Excitation			
	No Load	.8PF	
Excitation Voltage	4.8	41.3	
Excitation Current	3.7	10.5	
Voltage Regulation and Accuracy			
Voltage Level Adjustment	+/-5%		
Constant Speed	+/-1%		
with 3 % Speed Change	+/-2%		
Generator Resistances and Reactances			
	Resistances at 25 Degrees C		**Generator Impedance**
	Stator (ohms)	Field (ohms)	Base Ohms
	0.2008	0.8318	17.3056
Reactances			
		Per Unit	Ohms
Subtransient Direct Axis	X"D	0.1587	2.7459
Subtransient Quadrature Axis	X"Q	0.1498	2.519
Transient Saturated	X'D	0.2342	4.0533
Synchronous Direct Axis	XD	1.5949	27.6012
Synchronous - Quadrature Axis	XQ	0.8826	15.2731
Negative Sequence	X2	0.1542	2.6689
Zero Sequence	X0	0.0733	1.2683
		Seconds	
Open Circuit Transient Direct Axis	T'DO	2.76159	
Short Circuit Transient Direct Axis	T'D	0.40555	
Open Circuit Subtransient Direct Axis	T"DO	0.01652	
Short Circuit Subtransient Direct Axis	T"D	0.00239	
Open Circuit Subtransient Quadrature Axis	T"QO	0.00857	
Short Circuit Subtransient Quadrature Axis	T"Q	0.00012	
Armature Short Circuit	TA	0.02617	
Waveform Deviation Line-to-line No Load		Telephone influence Factor	
Less than 5%		Less than 50	
For Inertia Data Refer to TD6502			